ISSN 1346-7565 Acta Phytotax. Geobot. 60 (1): 56–59 (2009)

SHORT COMMUNICATION

First Report of Flexistyly in *Plagiostachys* (Zingiberaceae)

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Field observations of Bornean gingers have revealed that *Alpinia havilandii* and *Plagiostachys strobilifera* exhibit flexistyly—a novel floral strategy involving extreme stigmatic movement that enhances outcrossing. *Alpinia*, *Amomum*, and *Etlingera* are known to exhibit flexistyly; however, flexistyly in *Plagiostachys* has remained unconfirmed, although the genus was believed to possess this floral strategy. This report provides concrete evidence of flexistyly in *Plagiostachys*.

Key words: *Alpinia havilandii*, Borneo, flexistyly, *Plagiostachys strobilifera*

Flexistyly is a unique floral dimorphism that results in a change in the posture of the style over time (Cui *et al.* 1995, Li *et al.* 2001, 2002, Zhang *et al.* 2003, Takano *et al.* 2005, Sun *et al.* 2007, Ren *et al.* 2007). In cataflexistyly the flowers disperse pollen in the morning (protoandrous), and the style is curved upward so that the stigmata are not exposed to pollinators nor susceptible to self pollination. At noon, after the pollen has been shed, the style moves downward into a position where the stigmata can make contact with pollinators. In anaflexistylous (protogynous) flowers, the style is positioned to be in contact with pollinators in the morning before the pollen sacs dehisce. At noon, the style moves upward, and the pollen sacs begin to dehisce.

More than 20 species of gingers are known to exhibit flexistyly. Kress *et al.* (2005) state that flexistyly has evolved in the common ancestor of the tribe Alpinieae or has independently occurred at least three to five times in the tribe. Most studies on flexistyly have been on Chinese gingers, and more examples will probably be identified in the future. To obtain a more thorough understanding of the prevalence of flexistyly and its evolutionary origin in gingers, we conducted field surveys in Malaysia.

Materials and Methods

Field observations were carried out during November–December 2005 and in February 2006 at several sites in Sabah, northern Borneo. To confirm both cataflexistyly and anaflexistyly, we examined only species where flowering individuals occurred in large numbers at a site. We observed flowering individuals in the morning (0830–1030 hours) and in the afternoon (after 1300 hours) and recorded the position of the stigmata in relation to the anthers. Voucher specimens are deposited at BORH and HYO.

Results and Discussion

Ten genera and 42 species of gingers were observed during the study period (Table 1). Among them, *Alpinia mutica* Roxb., *Alpinia nieuwenhuizii* Valeton, *Alpinia havilandii* K. Schum. (Fig. 1A–D), and *Plagiostachys strobilifera* Ridl. (Fig. 1E–H) exhibited flexistyly. This is the first report of flexistyly in the latter two species. In *A. havilandii*, four flowering individuals were observed at Kinabalu Park Headquarters; cataflexistylous flowers were present on three individuals, while

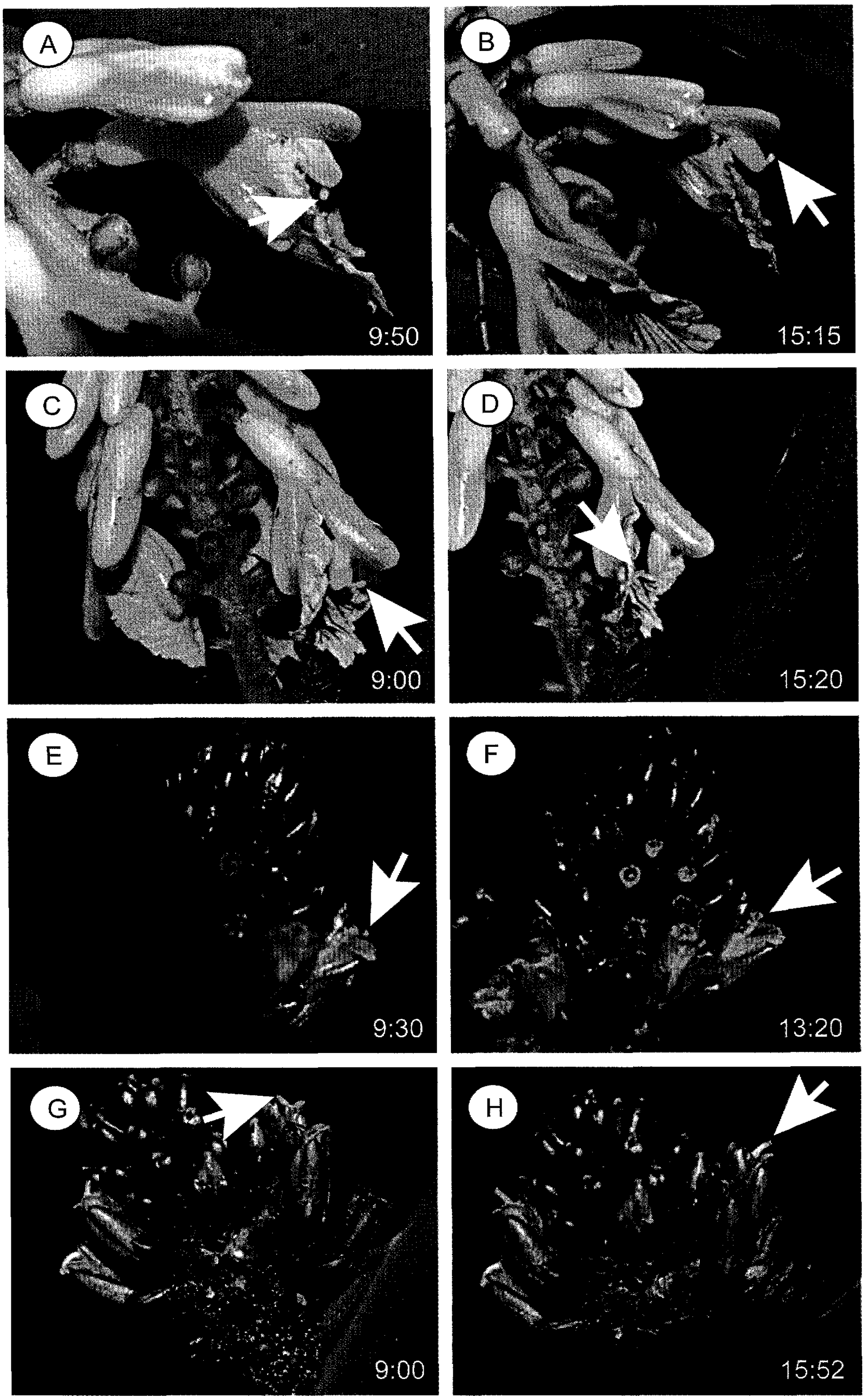

FIG. 1. A–D: Two floral morphs of *Alpinia havilandii*. Arrow indicates position of stigma. A: An anaflexistylous (protogynous) flower in morning; style is curved downward and stigmata are in receptive position. Pollen sacs not open. B: An anaflexistylous flower in afternoon. Stigmata are in upward position. C: Cataflexistylous (protandrous) flower in morning. Style curved upward, and stigmata are in unreceptive position. Pollen sacs have opened and have begun to release pollen. D: Cataflexistylous flower in afternoon. Style curved downward and stigmata are in receptive position. E–H. Two floral morphs of *Plagiostachys strobilifera*. E: An anaflexistylous flower in morning. Stigmata are in receptive position. F: An anaflexistylous flower in afternoon. Stigmata are in upward position. G: Cataflexistylous flower in morning. Stigmata are in upward position; pollen sacs have opened and have begun to release pollen. H: Cataflexistylous flower in afternoon. Stigmata are in receptive position.

TABLE 1. Species studied and the study sites. All sites are located in Sabah, northern Borneo.

Species	Study sites	Flexistyly?	Voucher specimens
Alpinia beamanii R. M. Sm.	Long Pasia	No	AT 300
Al. havilandii **K. Schum.**	HQ of Kinabalu Park	**YES**	TJJ 19
Al. mutica **Roxb.**	cultivated at ITBC, Univeristy Malaysia Sabah	**YES**	None
Al. nieuwenhuizii **Valeton**	Long Pasia	**YES**	AT 313
Amomum coriaceum R. M. Sm.	Tawau Hills Park	No	AT 346
Am. dimorphum N. F. Newman	Crocker Range	No	Cultivated at Kimanis substation
Am. gyrolophos R. M. Sm.	Danum Valley, Tawau Hills Park	No	AT 355 (Tawau), 371 (Danum)
Am. longipedunculatum R. M. Sm.	Mesilau, Kinabalu Park	No	TJJ 36
Am. testaceum Ridl.	Danum Valley	No	AT 369
Am. uliginosum Koen. ex Retz.	Tawau Hills Park	No	AT 335
Boesenbergia aurantiaca R. M. Sm.	Danum Valley	No	Cutivated at Danum Valley
B. grandifolia Loes.	Poring, Kinabalu Park	No	Living collction at Tropical Garden, Poring
B. pulchella Loes.	Crocker Range	No	TJJ 7
B. aff. *pulchella* Loes.	Tawau Hills Park	No	AT 345
Elettaria cf. *longituba* (Ridl.) Holttum	Tawau Hills Park	No	AT 324
Etlingera belalongensis A. D. Poulsen	Crocker Range	No	TJJ 18
Et. brevilabrum (Valeton) R. M. Sm.	Danum Valley	No	AT 365
Et. coccinea (Blume) S. Sakai & Nagam.	Long Pasia, Tawau Hills Park	No	AT 303 (Long Pasia), 352 (Tawau)
Et. corrugata A. D. Poulsen & Mood	Poring, Tawau Hills Park	No	AT 351 (Tawau), TJJ 41 (Poring)
Et. elatior (Jack) R. M. Sm.	Long Pasia	No	AT 316
Et. inundata S. Sakai & Nagam.	Tawau Hills Park	No	AT 342
Et. littoralis Gieseke	Danum Valley	No	Cultivated at Danum Valley
Et. muluensis R. M. Sm.	HQ of Kinabalu Park	No	Cultivated at garden of HQ
Et. nasuta (K. Schum.) R. M. Sm.	Long Pasia	No	AT 304
Et. velutina (Ridl.) R. M. Sm.	Crocker Range and Poring, Kinabalu Park	No	TJJ 4 (Crocker), 40 (Kinabalu)
Globba atrosanguinea Teijsm. & Binn.	Long Pasia	No	AT 310
G. francisci Ridl.	Tawau Hills Park	No	AT 325
G. pendula Roxb.	Long Pasia	No	AT 307
G. propinqua Ridl.	Long Pasia and Tawau Hills Park	No	AT 309 (Long Pasia), 326 (Tawau)
G. tricolor Ridl.	Crocker Range	No	None
Hedychium borneense R. M. Sm.	Long Pasia	No	AT 317
He. cylindricum Ridl.	Mesilau, Kinabalu Park	No	Cutivated at Mesilau Nature Resort
Hornstadtia incana R. M. Sm.	Crocker Range, HQ of Kinabalu Park	No	TJJ 9 (Crocker), 39 (Kinabalu)
Ho. cf. *tomentosa* (Blume) Bakh.f.	Danum Valley	No	AT 360
Ho. scyphifera Steud.	Long Pasia	No	AT 301
Plagiostachys albiflora Ridl.	Crocker Range, Danum Valley	No	AT 375 (Danum), TJJ 3 (Crocker)
P. longicaudata Julius & A. Takano	Crocker Range, Danum Valley	No	AT 364 (Danum), TJJ 12 (Crocker)
P. crocydocalyx (K. Schum.) B. L. Burtt & R. M. Sm.	Tawau Hills Park	No	AT 344
P. pseudobreviramosa ined.	Danum Valley	No	AT 359
P. strobilifera **Ridl.**	Danum Valley	**YES**	AT 358
Zingiber viridiflavum Mood & I. Theilade	Danum Valley	No	Cultivated at Danum Valley

Collector's abbreviations: AT = Avelinah Julius & Atsuko Takano, TJJ = Atsuko Takano, Julianah Awang, Johnny Gisil.

anaflexistylous flowers were observed on one individual (Fig. 1A–D). In *P. strobilifera,* six flowering individuals were observed at Danum Valley; three exhibited cataflexistyly and three exhibited anaflexistyly (Fig. 1E–H).

This paper provides the first concrete evidence of flexistyly in *Plagiostachys.* According to Kress *et al.* (2005), flexistyly is currently documented in 24 species of Zingiberaceae. Species of *Alpinia*, *Amomum*, and *Etlingera* are among those that exhibit flexistyly. They also speculated that flexistyly might occur in *Plagiostachys* and *Paramomum*, citing Cui *et al.* (1996). Cui *et al.* (1996) studied breeding systems in *Amomum tsao-ko* Crevost & Lemarie and reported flexistyly in *A. tsao-ko* and *Alpinia blepharocalyx* K. Schum. var. *glabrior* (Hand.-Mazz.) T. L. Wu. Although they (Cui *et al.* 1996) discussed the possibility of flexistyly in *Paramomum* and *Plagiostachys*, which are closely related to *Alpinia*, they provided no evidence to support their suspicions. Hence, this is the first concrete report of this floral dimorphism in *Plagiostachys.*

Plagiostachys is distinguished from other genera of Zingiberaceae by the apparently lateral, extremely congested inflorescence, which is, in fact, terminal on short stems from leafy shoots that usually break through the leaf sheaths just above ground level or occasionally from the middle of the plant (Smith 1990). Kress *et al.* (2002 & 2005) showed that *Alpinia* is polyphyletic and *Plagiostachys* is embedded within one of the *Alpinia* clades. Our recent molecular phylogenetic analyses on the increasing number of species of *Plagiostachys* and *Alpinia* also showed that *Plagiostachys* formed a well-supported clade (96% Bootstrap frequency) that included several species of *Alpinia* (Julius *et al.* 2008). The fact that flexistyly was detected in *Plagiostachys* may also indicate affinity to *Alpinia*, but further studies are required to redefine these generic boundaries.

We sincerely thank the Economic Planning Unit, which approved our research (UPE: 40/200/19/1358). The management of Sabah Parks and Sabah Foundation provided us with research facilities and extended their best cooperation. Dr. D. Boufford and two anonymous reviewers gave helpful suggestions on an earlier versions of the manuscript. This study was funded by a grant from the Japan Society for the Promotion of Science (BioTropical resources) to Atsuko Takano.

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Received December 24, 2008; accepted January 7, 2009